S282 Astronomy

Galaxy classification

Study time: 30 minutes

Summary

In this activity you will classify galaxies into the various Hubble classes described in Chapter 2 of *An Introduction to Galaxies and Cosmology*. This activity uses a set of images of nearby galaxies which is provided on the Image Archive on the S282 DVD.

You will also need a transparent ruler marked in millimetres.

You should have read to the end of Section 2.2 of *An Introduction to Galaxies and Cosmology* before starting this activity.

Learning outcomes

- To be able to classify galaxies according to the modified Hubble scheme.
- To appreciate that there is some degree of subjectivity in the classification process.

The activity

You will use the Hubble classification scheme described in Section 2.2 of *An Introduction to Galaxies and Cosmology* to classify galaxies by their morphology, using images from major observatories around the world provided in the Image Archive.

- Start the S282 Multimedia guide, and open the folder called 'Galaxies', then click on the icon for Galaxy classification.
- Press the Start button to launch the Image Archive at the required set of images.
- Alternatively, launch the Image Archive by clicking the Image Archive, button in the Multimedia guide and then find the Galaxy Classification set which is located within the Galaxies section of the archive.

You should now see 24 thumbnail negative images of galaxies. As usual, you can move the cursor across the images to see what they are – the NGC (New General Catalogue) number will appear – and you can obtain a larger image of each by clicking on the thumbnail. The first thing you will do is classify the galaxies roughly into the Hubble classes.

- What are the four major Hubble classes?

❑ Elliptical, lenticular, spiral and irregular; lenticular and spiral are also divided into barred and unbarred subclasses.

You will then determine the Hubble types of a selected number of galaxies.

Question 1

First, recall the Hubble types and note them down for each class in Table 1, giving a brief description of each class and its types, as in the example of the lenticular class shown.

Table 1 Descriptions of the Hubble classes and types (for use with Question 1).

Hubble class		Hubble types	Characteristics determining the class and type
Elliptical			
Lenticular	Unbarred Barred	S0 SB0	Lens-shaped with disc and nuclear bulge but no spiral arms. The bulge of an S0 galaxy is a spheroid, but that of an SB0 is a bar.
Spiral	Unbarred Barred		
Irregular			

Table 2 corresponds to the grid of 24 thumbnail images on the Image Archive. Fill it in with the Hubble classes and types as you work through the activity (or make a separate note of your classifications).

The symbols ^{X} and * indicate the order in which we suggest you classify the galaxies: we will work through those marked with ^{X} as examples to get you going, and then leave you to work through the classification of those marked with * with a discussion of how each one is classified at the end of the activity. The rest we leave as an optional exercise (though we will give you the answers!)

Table 2 The grid of thumbnail images in the order in which they are displayed in the Image Archive.

NGC 7814	NGC 0024	NGC 0134	NGC 0147	NGC 0148*	NGC 0150*
NGC 0157	NGC 0185	NGC 0205*	NGC 0210^{X}	NGC 0221	NGC 0255
NGC 0278	NGC 0488*	NGC 0514	NGC 0524	NGC 0615	NGC 0636*
NGC 0681*	NGC 0720^{X}	NGC 1052	NGC 1073*	NGC 1156*	NGC 1172

Example 1: NGC 0210

Well, I hope you agree that this is a spiral galaxy! But let's be a little more systematic: to determine the Hubble class ask yourself:

- Is there any overall regularity or symmetry?

- Yes. The galaxy appears to be an ellipse, and would look the same if you turned it upside down. So it can't be an irregular.

- Is there any internal structure?

- Yes. There is a clearly defined bright nuclear bulge in the centre, surrounded by two impressive spiral arms. (Remember that the images are negative so the bright features look dark.) So it can't be an elliptical.

- Are there any spiral arms?

- As above, yes. So it's not lenticular, but spiral.

This means that the true shape is a circular disc with a nuclear bulge. The disc appears in the image to be an ellipse rather than a circle so we're not looking face on to it but at an angle; this angle of inclination is a little over 45°. The largish bright object at the 4 o'clock' position is a foreground star in our Galaxy, but the spiral arms contain many small bright HII regions, probably of star formation. Furthermore the spiral arms are branched towards their ends. There is no sign of a central bar, so this galaxy is an S, not an SB.

Determining the Hubble type of a spiral is quite hard and also quite subjective – if you look them up in different sources you don't always get the same answer!

(I find that one way to remember the order of Sa – Sc is that the arms of Sa are tightly wound like the symbol '@', whereas the arms of Sc are loosely wound like C.) As well as looking at how tightly the arms are wound, you need to look at the relative size of the nuclear bulge. Here, the arms are quite definitely wrapped around the fairly large nuclear bulge, so it's unlikely to be Sc, but at the same time they are reasonably open – you can see space between the arms and bulge, so it's unlikely to be Sa.

Hence for NGC 0210 we assign the Hubble type Sb.

Example 2: NGC 0720

This looks quite different from the previous example. Again let's be systematic in determining the Hubble class:

- Is there any overall regularity or symmetry?

- Yes. The galaxy appears to be a smooth ellipse, so it can't be an irregular.

- Is there any internal structure?

- No, not really. There are no distinct features, but the brightness is concentrated in the centre and decreases steadily towards the edge of the galaxy. Indeed as it fades out, you can't really say where the edge is. So it is an elliptical galaxy, E.

- Are there any spiral arms?

- No, and you wouldn't expect them in an elliptical galaxy.

With practice you can judge the Hubble type just by looking at the shape of the ellipse, but to start with you will be better off measuring the axes and calculating the flattening factor.

Recall that the type of an elliptical galaxy is defined as the nearest whole number to $10 \times (a - b)/a$, where $(a - b)/a$ is the flattening factor, calculated from the semimajor axis a and the semiminor axis b of the visible ellipse (Section 2.2.1). You can measure these directly on the images; since you are dividing one length by another, the result is a dimensionless ratio (it has no unit) and so it doesn't matter that you are measuring the image rather than the real thing (which would be a little difficult!).

In fact, you can measure the major and minor axes – again, since you are calculating a ratio, it doesn't make any difference whether you measure $2a$ and $2b$ instead of a and b, you will get

$$\frac{2a-2b}{2a} = \frac{2(a-b)}{2a} = \frac{a-b}{a}$$

as required.

The tricky bit is deciding just where to measure the axes. As we have said, it's hard to say where the edge of the galaxy is. So you have to imagine a contour line of equal surface brightness around the centre region – an *isophote* – and measure the axes of that.

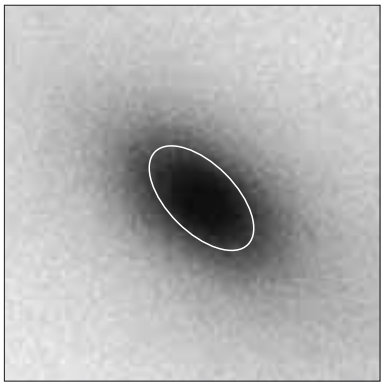

Figure 1 An isophote superimposed on NGC 0720.

You could try measuring directly from the screen, but it is better to print the image, and then sketch in an isophote and measure this. (Don't worry about the black surround of the image, the surround prints as white.)

I got the major axis, $2a = 35$ mm, minor axis, $2b = 18$ mm, so the flattening factor

$$\frac{a-b}{a} = \frac{(35-18)\text{ mm}}{35\text{ mm}} = 0.49$$

(Your choice of an isophote is likely to differ from mine, and so your measurements may be quite different, but the final flattening factor should be similar.)

To get the Hubble type, we have to multiply the flattening factor by 10 and round to the nearest whole number: $0.49 \times 10 = 4.9 \sim 5$.

So for NGC 0720 we assign the Hubble type E5.

Don't be disappointed if your Hubble types for these two examples are slightly different from those given here. I'm sure you will have realized by now that judging just where to measure the axes of an elliptical is just as difficult as deciding how tightly wound the arms of a spiral are, and how large is its nuclear bulge. Even the experts sometimes disagree!

Question 2

Now have a go at classifying a few more galaxies yourself. Try the following eight, which give a good spread of types (these are the ones marked with * in Table 2):

NGC 0148, NGC 0150, NGC 0205, NGC 0488, NGC 0636, NGC 0681, NGC 1073, NGC 1156.

Have a look at the answers if you get stuck.

Question 3 (optional)

Finally, you might like to try classifying the remaining 14 galaxies in the galaxy classification section. The accepted classes and types are shown in Table 4 in the answers.

Answers to questions

Question 1

The answer is given in Table 3.

Table 3 Descriptions of the Hubble classes and types. (The completed Table 1.)

Hubble class		Hubble types	Characteristics determining the class and type
Elliptical		E0 – E7	Overall elliptical outline, featureless appearance, light output concentrated in centre, decreasing as you move outwards. The number gives 10 × the flattening factor – E0 appears circular, E7 is the most flattened.
Lenticular	Unbarred Barred	S0 SB0	Lens-shaped with disc and nuclear bulge but no spiral arms. The bulge of an S0 galaxy is a spheroid, but that of an SB0 is a bar.
Spiral	Unbarred Barred	Sa, Sb, Sc SBa, SBb, SBc	Circular disc (though may appear elliptical) with spiral arms and nuclear bulge. SB types have central bar as above. The letters a, b, c show how tightly wound the spiral arms are and how big the nuclear bulge is – Sa, SBa are tightly wound with a large bulge, Sb, SBb less so and Sc, SBc loosely wound with a small bulge.
Irregular		Irr	No symmetry or regularity.

Question 2

The classifications are discussed below.

NGC 0148

- Is there any overall regularity or symmetry?
- Yes. The galaxy isn't quite an ellipse but it's certainly symmetrical, so it can't be an irregular.
- Is there any internal structure?
- Yes. There is a distinct nuclear bulge, and a slight indication of a darkening between the bulge and the ends of the major axis. (Remember the image is a negative, so a darkening appears lighter). This is consistent with a disc with a bright outer ring; the darkening could be due to less bright matter or obscuring dust. The angle of inclination is so great (nearly 80°) that the bulge extends above and below the disc, giving it a not quite elliptical shape. So it is not an elliptical.
- Are there any spiral arms?
- No, we can see no evidence of actual spiral arms. So it is not a spiral but a lenticular.

There is no evidence either of a bar in the bulge, so this is an unbarred lenticular S0 galaxy.

NGC 0150

- Is there any overall regularity or symmetry?
- Well, it's not perfectly symmetrical, but there is a sort of regularity about it, so we'll leave the classification 'irregular' aside for the moment.
- Is there any internal structure?
- Yes. There is evidently a disc of two or three spiral arms, quite tightly wound, but one of the arms spoils the symmetry, possibly rising out of the plane of the disc. There also seems to be a small bright nuclear bulge. So it is some kind of a spiral galaxy.

Despite the small nuclear bulge, which would tend to indicate Sc, the arms are really too tightly wound for this classification, so I would classify it as Sbc. Some (but not all) observers claim to detect a bar, and it is sometimes classified SBb. The strange asymmetrical rising third arm also qualifies it as a *peculiar* galaxy, so the full Hubble type I would give is Sbcp.

NGC 0205

- Is there any overall regularity or symmetry?
- Yes. The image of the galaxy has an elliptical shape. So it's not an irregular.
- Is there any internal structure?
- Not in the sense of a nuclear bulge or spiral arms. It looks like a typical elliptical in the sense of a generally bland appearance with the brightness concentrated in the centre and decreasing steadily towards the edge. But if you look closely you will see that there are a couple of darkened (i.e. pale-looking in the negative) patches on the right-hand side. These are dust patches, and dust, like gas, is rare in elliptical galaxies.
- Are there any spiral arms?
- No. So it isn't a spiral.

The dust patches, together with other unusual features for ellipticals such as bright young stars which aren't really visible in this image, have led many observers to classify this as a lenticular, S0. But other observers stick with the perhaps more obvious classification as an elliptical. With a major axis of around 40 mm and a minor axis of 21 mm, the flattening factor is 19/40 = 0.48, so the Hubble type is E5, or E5p to take account of the peculiar feature of the dust patches.

This galaxy is M110, one of the dwarf companions of M31, the Andromeda Galaxy.

NGC 0488

I hope you agree that this is a spiral. The nuclear bulge is quite large and the thin multiple arms contain many small lumpy bright patches, indicating star formation. The arms are quite tightly wound, giving it the Hubble type Sab.

NGC 0636

I hope you agree also that this is an elliptical. It is not quite circular; the 10 o'clock – 4 o'clock axis is slightly longer than the 1 o'clock – 7 o'clock axis, giving a Hubble type of E1. What looks like a small satellite galaxy at 7 o'clock is actually an offset secondary image of the small bright nucleus of NGC 0636 itself.

NGC 0681

This is a bit trickier. Let's go back to the systematic approach:

- Is there any overall regularity or symmetry?
- Yes. The two sides are more or less mirror images of each other.
- Is there any internal structure?
- Yes. There is a bright extended nuclear bulge with a darkened thick dust lane obscuring the bottom half of it. This is consistent with a disc seen almost edge on.
- Are there any spiral arms?
- Difficult to say, because of the angle and the obscuring dust, but at the sides of the nuclear bulge it looks as though there may be spiral arms in the disc.

The relative sizes of the nuclear bulge and the disc, and the general impression of not too tightly wound arms lead to a classification as Sb or Sab.

NGC 1073

Once again, this is clearly a rather beautiful spiral, seen almost face on. The nuclear bulge is small and distinctly barred, and the arms are open and branched. Hubble type SBc.

NGC 1156

- Is there any overall regularity or symmetry?
- Not really. It is vaguely peanut shaped, with bright lumpy star forming regions. The star formation indicates that it is not an elliptical. Some observers claim to see it as a bar, others claim to see rudimentary spiral structure. But the general classification is as an irregular – Irr.

Question 3

The answer is given in Table 4.

Table 4 The completed grid of galaxy classifications.

NGC 7814 spiral edge-on possibly Sab	NGC 0024 spiral Sc	NGC 0134 spiral Sbc	NGC 0147 elliptical E5	NGC 0148* lenticular S0	NGC 0150* spiral/pec Sbcp
NGC 0157 spiral Sc	NGC 0185 elliptical E3	NGC 0205* elliptical/ lenticular E5p/S0	NGC 0210^{X} spiral Sb	NGC 0221 elliptical M32 E2	NGC 0255 barred spiral SBc
NGC 0278 spiral Sbc	NGC 0488* spiral Sab	NGC 0514 spiral Sc	NGC 0524 lenticular S0	NGC 0615 spiral Sb	NGC 0636* elliptical E1
NGC 0681* spiral Sab/Sb	NGC 0720^{X} elliptical E5	NGC 1052 elliptical E4	NGC 1073* barred spiral SBc	NGC 1156* irregular Irr	NGC 1172 elliptical/ lenticular E1/S0

Acknowledgement

Figure 1 From *The Carnegie Atlas of Galaxies*, Volume I, A. Sandage and J. Bedke, 1994, Carnegie Institution of Washington – obtained from NASA Extragalactic Database.